PATENT SPECIFICATION (11) 1 591 624

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(21) Application No. 2750/77 (22) Filed 24 Jan. 1977 (19)

(23) Complete Specification Filed 11 Jan. 1978

(44) Complete Specification Published 24 Jun. 1981

(51) INT. CL.[3] H03H 9/15

(52) Index at Acceptance
H3U 22 26Y 28 29B 29Y 35 ES

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(54) ACOUSTIC WAVE DEVICES

(71) I, SECRETARY OF STATE FOR DEFENCE, London do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to acoustic wave devices in which acoustic waves are caused to travel in the bulk of a substrate between two transducers.

In U.K. Patent Specification Number 1,451,326 an oscillator is described which comprises an acoustic wave delay line in the feedback loop of an amplifier. This delay line comprises a piezo electric substrate carrying two interdigital comb transducers which can launch and receive surface acoustic waves along or in the surface between the transducers. Alternatively, when using quartz slices orientated at right angles to the AT-cut plane and to the YZ-plane the delay line can operate using bulk acoustic waves i.e. waves travelling beneath the substrate surface. This gives insensitivity to surface contamination.

According to this invention a bulk acoustic wave device comprises a quartz piezo electric substrate having a flat surface which carries at least two transducers for launching and receiving acoustic waves into and from the bulk of the substrate between the two transducers, the flat surface lying in a plane that is rotated about the X axis (a rotated Y-cut) by an amount in the range $-55°$ to $-48°$ or also the range $30°$ to $40°$ with the transducers arranged to provide a propagation of acoustic wave vector that is perpendicular to the X axis.

Preferably the transducers are interdigital comb transducers.

Transducers may launch a number of types of bulk acoustic waves into a substrate, this is discussed in 1977 Ultrasonic Symposium Proc, papers T1, T2 articles Surface Skimming Bulk Waves by M.F. Lewis, and Bandpass Filters by T.I. Browning, D.J. Gunton, M.F. Lewis, and C.O. Newton. One type of bulk acoustic wave travels at and below the surface approximately parallel thereto, it has been termed a surface skimming bulk wave (SSBW) and is a horizontally polarised shear wave. Another SSBW is a longitudinal wave.

The following properties are desirable or necessary for a surface skimming bulk wave device:

1. No surface acoustic wave coupling;
2. Shear wave of quasi shear wave polarised in the plane of the surface, this is necessary to prevent leakage of energy into the volume of the substrate;
3. A good k^2 for the bulk waves 2, above with a small coupling to other bulk waves;
4. Zero temperature co-efficient for bulk waves.
5. No beam steering or focussing properties.

One class of cuts satisfying 1, 2, 5 is the rotated Y-cuts of quartz (i.e. rotated about X axis) with propagation perpendicular to the X axis. This whole class has $k^2 = 0$ for surface acoustic waves. It has a shear wave polarised in the X direction i.e. in the plane, which is necessary for the wave to propagate without series leakage of energy into the substrate. Also within the class, two ranges of angles of rotation of the Y-cut satisfy condition 4. These ranges are $-48°$ to $-55°$ rotated Y cut which supports a shear wave with velocity about 3.3×10^5 cm/sec (closely analogous to the shear wave used in the normal AT cut bulk wave oscillator) and also the range $30°$ to $40°$ which supports a shear wave with velocity about 5.2×10^5 cm/sec (and closely analogous to the shear wave used in the normal BT cut bulk wave oscillator). Acoustic wave devices exhibit a frequency change with substrate temperature change thereby limiting the usefulness of some devices. These rotated Y cut quartz devices

show a zero temperature co-efficient, i.e. a zero frequency change with changing substrate temperature, at a temperature value or range which is dependent on the angle of rotation. For example zero temperature coefficient for a number of quart cuts occurs as follows:

Rotation degree	*Temperature °C*
− 49	− 30
− 49.5	− 10
− 50	+ 10
− 50.5	+ 40
−50.5 to − 51	Over 60 extending for a range of temperatures
35	− 10
35.3	+ 15
36	30
36.5	50
37	70

The particular delay structure used to obtain the above results had an acoustic path 2,500 λ long and a transducer length of 2,500 λ with periodically thinned (missing) finger pairs, λ being wavelength. Different transducer structures modify the above values. For rotated Y cuts in the above ranges with propagation perpendicular to the X axis, the acoustic propagation is symmetrical about the propagation direction so that the energy travels parallel to the *k* vector (i.e. no beam steering) and this also makes for insensitivity to small misorientations in manufacture.

The class of cut with a shear wave velocity of 5.1 x 10^5 cm/sec is particularly attractive for high frequency oscillators. One has been made which showed a parabolic frequency temperature variation (a 35.3° rotated Y cut) with inversion temperature at 20°C, measured on an oscillator having a delay line of path length 2,500 λ wavelengths.

The invention will now be described by way of example only with reference to the drawings accompanying the Provisional Specification.

Figure 1 shows some planes of cuts in quartz;

Figure 2 shows a plan view of a bulk acoustic wave device connected to an amplifier to form an oscillator.

Figure 3 shows an end view of Figure 2.

The three orthogonal axes of a crystal are shown in Figure 1. A Y-cut plate is one whose operating surface lies in the Z, X plane. If the plane is rotated by 35.3° about the X axis it is termed an AT-cut. Another cut is termed the BT-cut. Yet another is the ST-cut. The cuts used for bulk waves of this invention are about perpendicular to the AT-cut or BT-cut since the bulk waves are propagated approximately parallel to the flat surface and not across a thickness of a thin plate as in conventional bulk wave devices.

As shown in Figures 2, 3 a delay line comprises a quart substrate 1 with a flat upper surface 2 orientated as hereinbefore defined. The bottom surface 3 is preferably angled by a few degrees and roughened to prevent reflections interfering with the wanted bulk waves. Two interdigital transducers 4, 5 are mounted on the flat surface 2. As an example the transducers may each have 90 finger pairs and be separated (centre to centre) by a distance almost equal to the transducer length to give mode suppression as taught in U.K. Patent 1,451,326. An amplifier 6 is connected between the transducers 4, 5. The whole device may be encapsulated within a plastics material.

In operation surface skimming bulk acoustic waves are launched by transducer 4 into the substrate. These SSBW travel beneath the surface 2 and are transduced back into electrical signals by transducer 5. Since the transducers 4, 5 are close together good coupling into and from the substrate occurs. However other transducer configurations are possible, for example ladder types as taught in U.K. 1,451,326.

The invention is not limited to oscillators but can be used in place of surface acoustic wave delay lines and in many filter applications.

Substrates other than quartz may be used for example $LiNbO_3$ and $LiTaO_3$ but the cuts used must be orientated to give properties listed at 1 to 5 above. For $LiTaO_3$ these include approximately + 36° ± 3° and − 54° ± 3° (orthogonal) rotated (about X-axis) Y-cuts containing the directions of polarisation of the shear bulk waves which propagate along the X-axis of the crystal (as calculated for an infinite medium). The acoustic wave propagation is in the X-direction. For $LiNbO_3$ the cuts are 45° ± 5° and − 45° ± 5° rotated Y cuts, propagation is in the X direction. It is pointed out however that devices with a substrate of lithium niobate or lithium tantalate do not fall within the scope of the present invention. Devices using lithium tantalate as a substrate are claimed in co-pending application No. 2181/80 Serial No. 1591625.

It should be understood that this list of properties can be departed from slightly since they are ideal, e.g. a small amount of surface wave coupling can be tolerated (and removed by surface mounted absorbers) but it is preferably as low as possible.

WHAT I CLAIM IS:-

1. A bulk acoustic wave device comprising a quartz piezo electric substrate having a flat surface, an input transducer and an output transducer mounted on the flat surface for respectively launching acoustic waves in and receiving acoustic waves from the bulk of the substrate, the flat surface lying in a plane that is rotated, about the crystalline X axis, a rotated (Y-cut) by an amount in the range −55° to −48° or 30° to 40° with the transducers arranged to provide a propagation of acoustic wave vector that is perpendicular to the X axis.

2. A device as claimed in claim 1 wherein the rotation of cut is in the range −51° to −49° inclusive.

3. A device as claimed in claim 1 wherein the transducers are interdigital finger comb transducers.

4. A device according to claim 1 wherein the substrate has a face opposite said flat surface which is not parallel to said flat surface.

5. A device as claimed in claim 1 and further comprising an absorber mounted on the flat surface between the transducers.

6. An acoustic wave device as claimed in claim 1 constructed arranged and adapted to operate substantially as hereinbefore described with reference to the drawings accompanying the Provisional Specification.

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Agent for the Applicant.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1981.
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1591624 PROVISIONAL SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

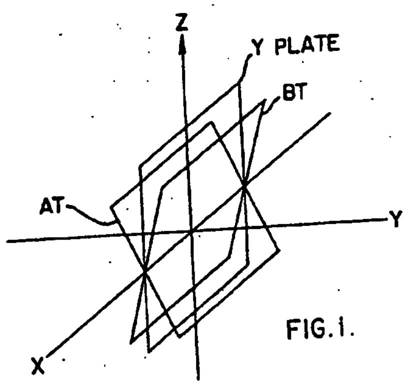

FIG. 1.

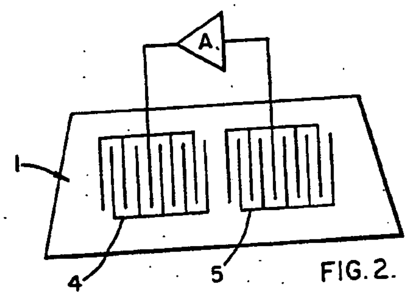

FIG. 2.

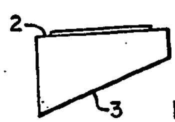

FIG. 3.